The Seismic Performance of Smooth Reinforcing Bars in RC Columns

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The use of Grade 80 steel is currently restricted in members that form plastic hinges

3.3.3 Reinforcing Steel

ASTM A706 reinforcing steel shall be used for seismic applications, as follows:

- ASTM A706 Grade 60 – for all applications, including use in SCMs and capacity protected members. Hooks, headed bar terminations, and splices shall be allowed.
- ASTM A706 Grade 80 – for straight bars in capacity protected members only. A PSDC shall be required to use Grade 80 reinforcing steel for hooks, headed bar terminations, splices, and couplers.

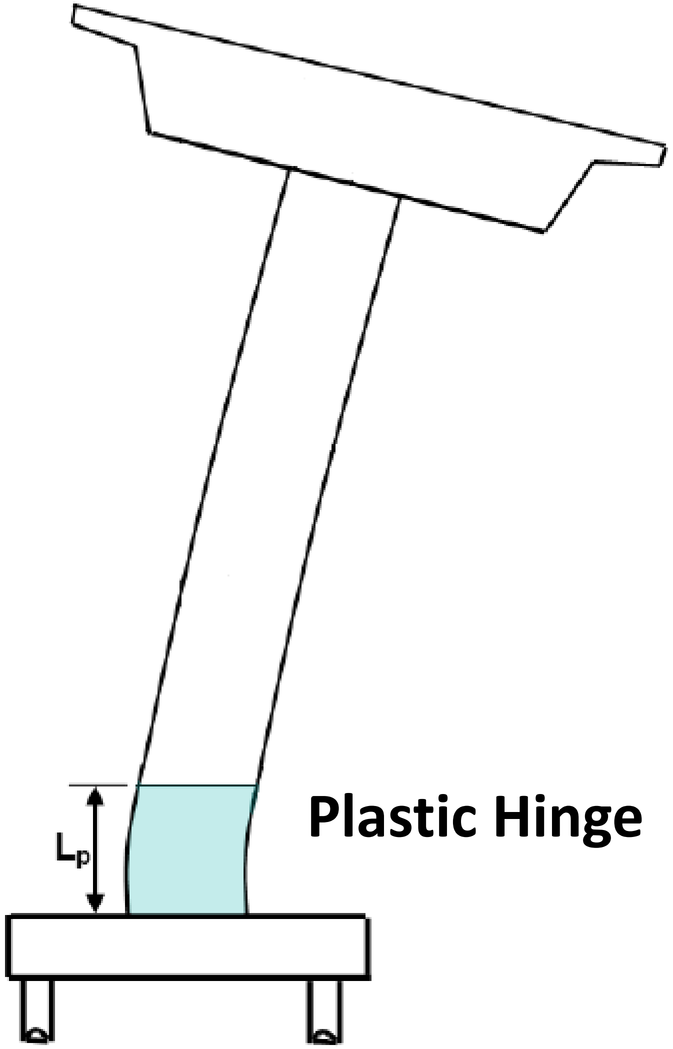
C3.3.3

Grade 80 bars are not to be used in SCMs until definitive data from ongoing research become available.

Use of Grade 80 reinforcing steel for headed bar terminations, hooks, and couplers may be permitted on a project specific basis (PSDC) based on availability of specific project data.

The properties for A706 Grade 60 reinforcing steel were established on the basis of data from a collection of mill certificates and augmented by testing conducted by Caltrans Material Engineering and Testing Services (METS).

Caltrans SDC



Caltrans (2019)

Also restricted in Oregon (ODOT), Washington (WSDOT), and AASHTO Seismic Guide Specs

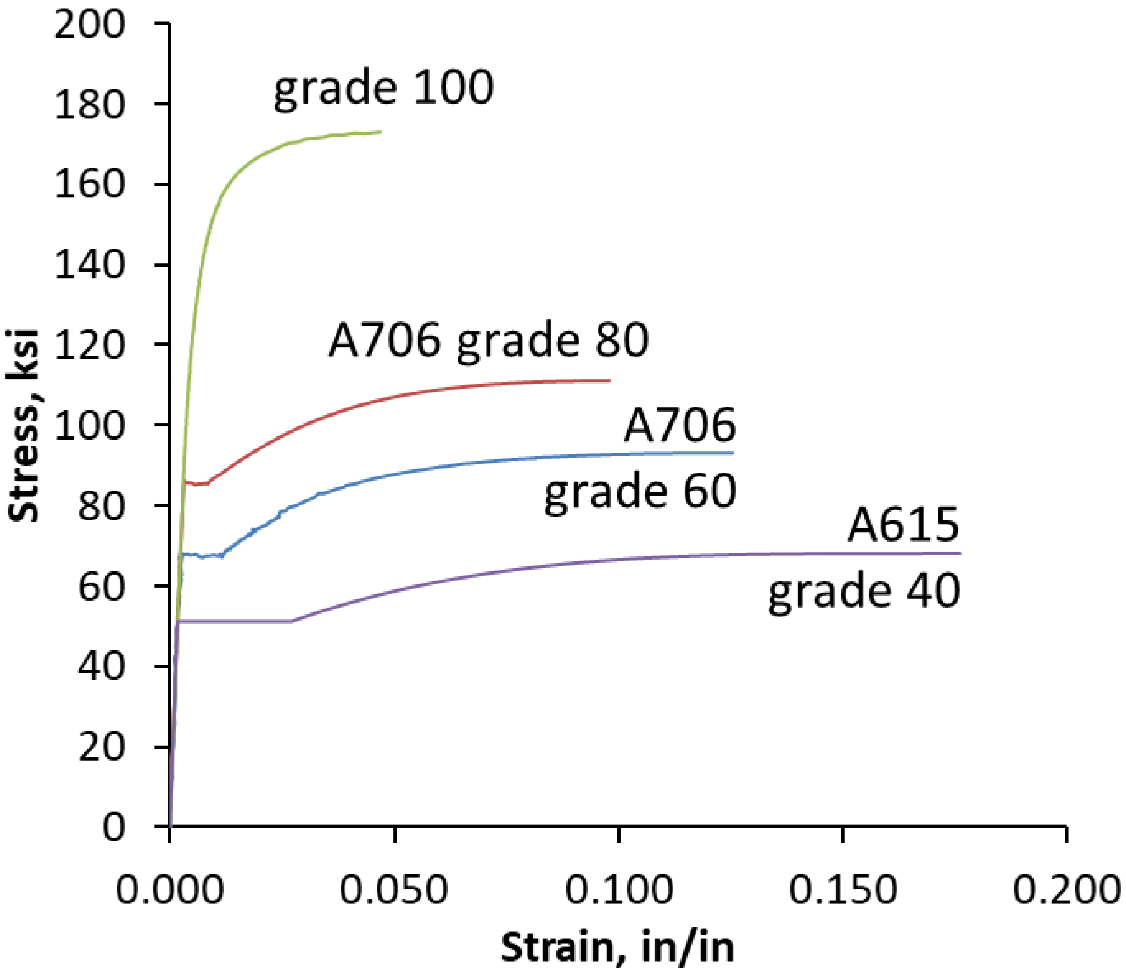
Higher strength steel can lead to more efficient designs which reduce congestion and improve confinement

concreteconstruction.net

It can also lead to reduced cost, construction times, and improved scheduling

Why is Grade 80 reinforcing steel restricted in members that form plastic hinges?

Grade 80 steel has at least 33% less uniform elongation compared to Grade 60 steel

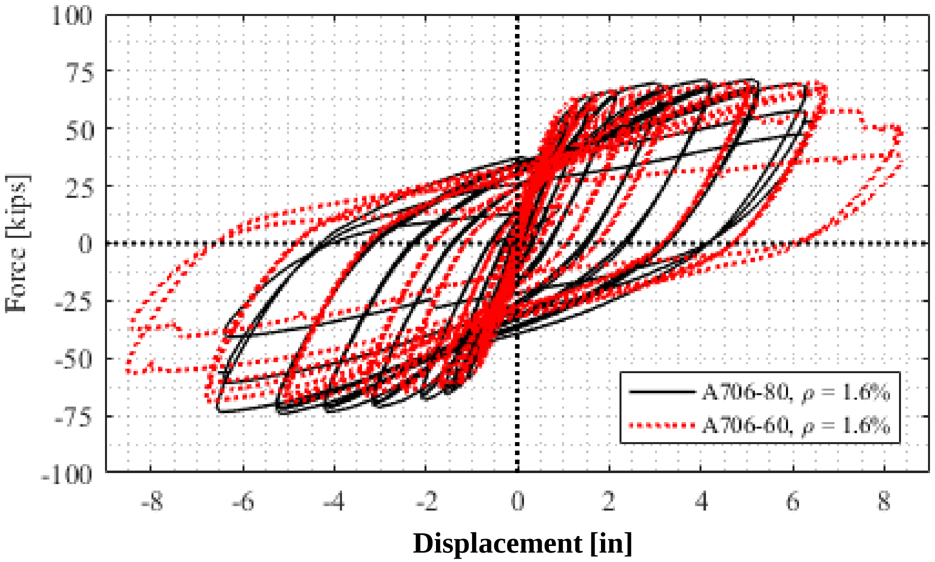


Overby et al. (2017)

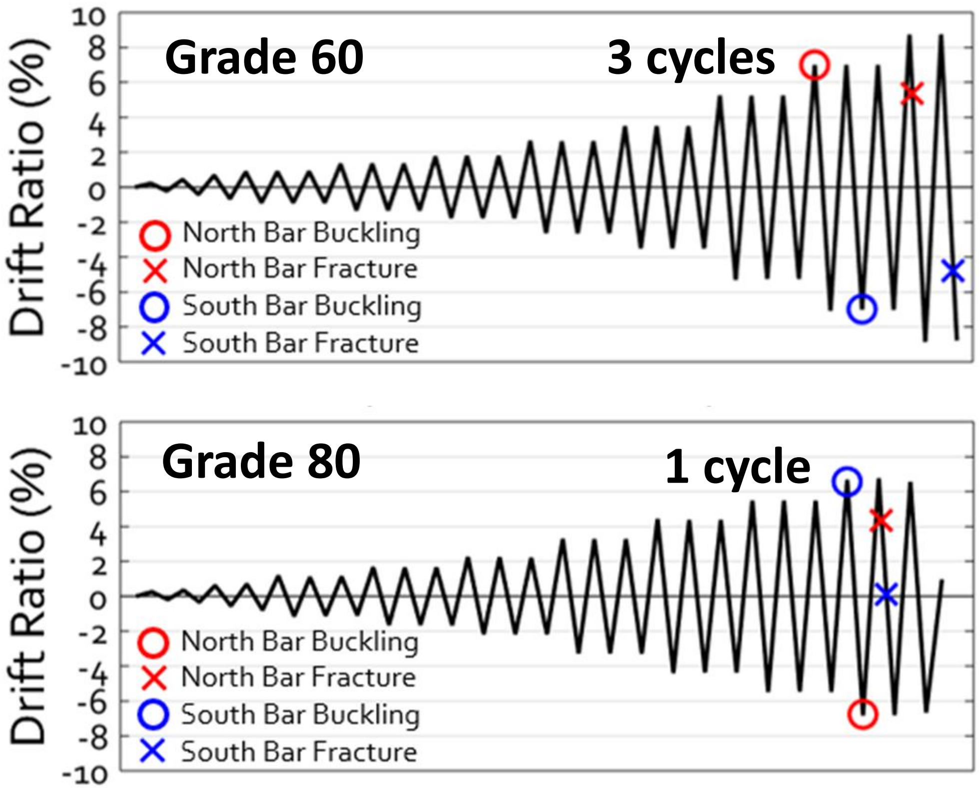
Four large-scale reverse cyclic columns tests reinforced with A706-80 steel were conducted

Differences to Grade 60 steel include <u>lower</u>:

Displacement capacity

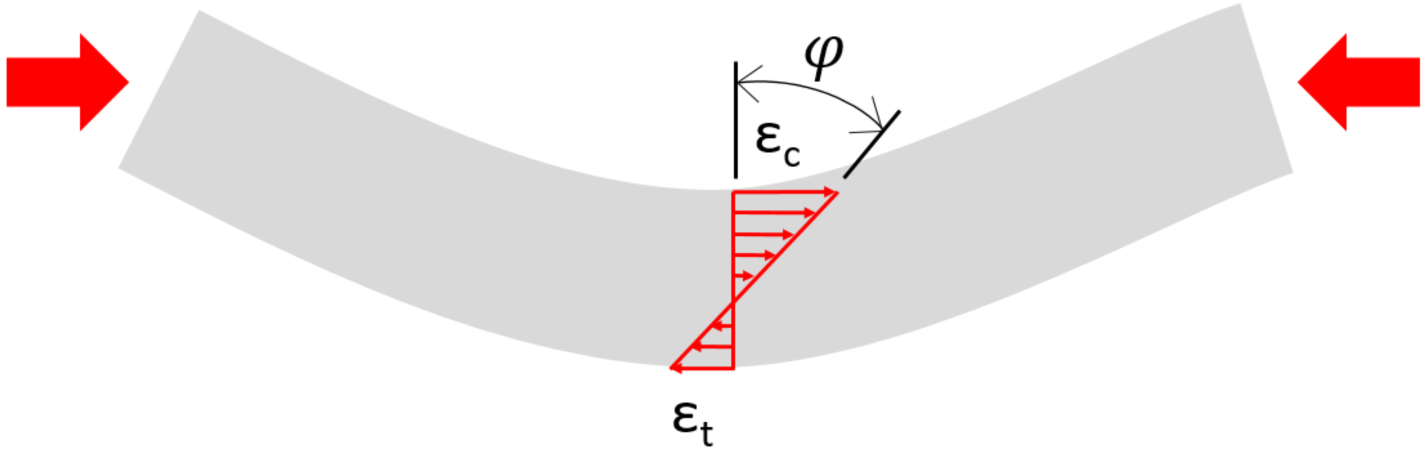


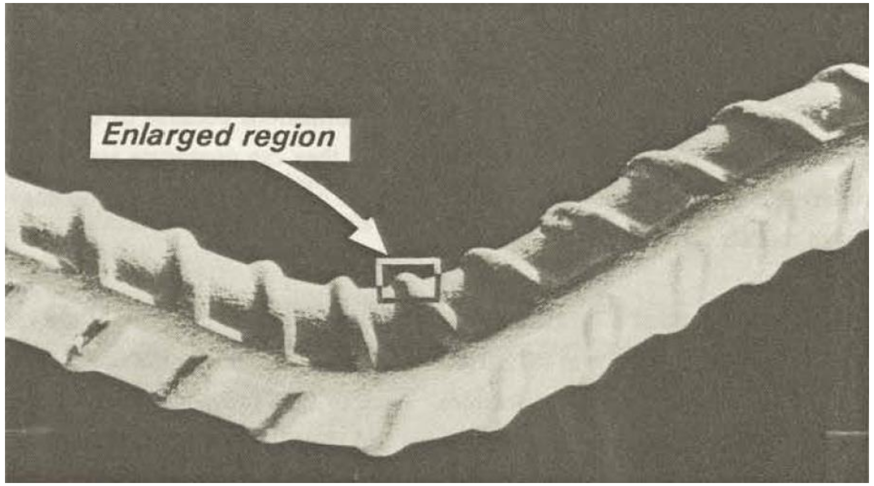
Post-buckling cycles until fracture

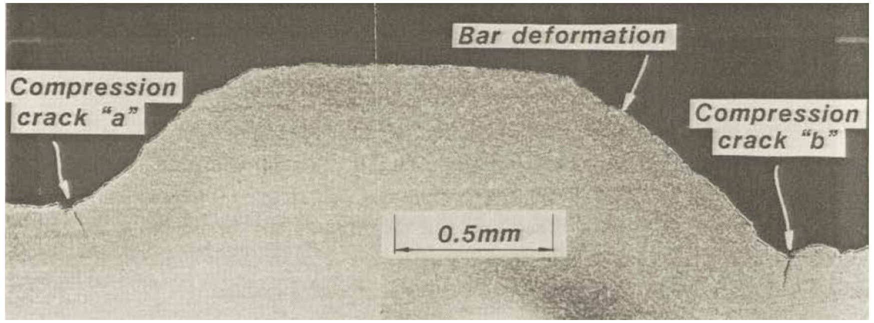


Barcley and Kowalsky (2018)

Difference in displacement capacity and post-buckling behavior attributed to “bending strain capacity”







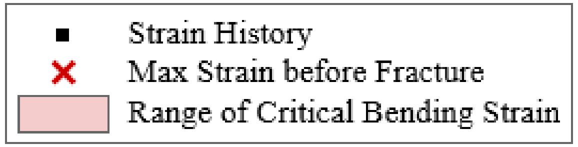
Restrepo-Posada (1993)

Bending strain capacity

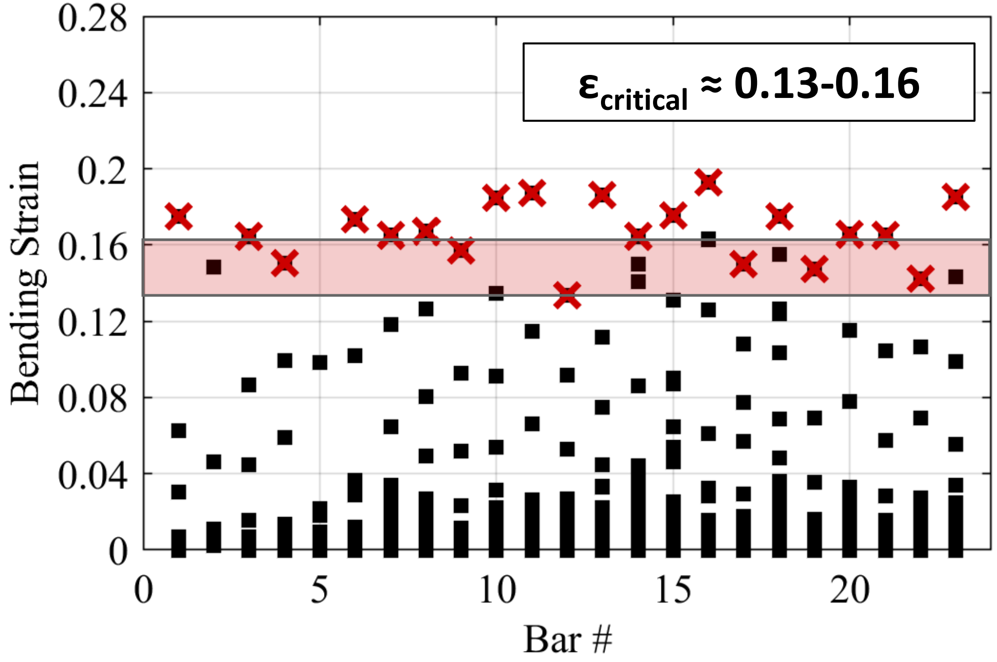
$$\boldsymbol{\varepsilon \approx \varphi \times \frac{d}{2}}$$

If bar is substantially buckled, crack will propagate upon subsequent tension

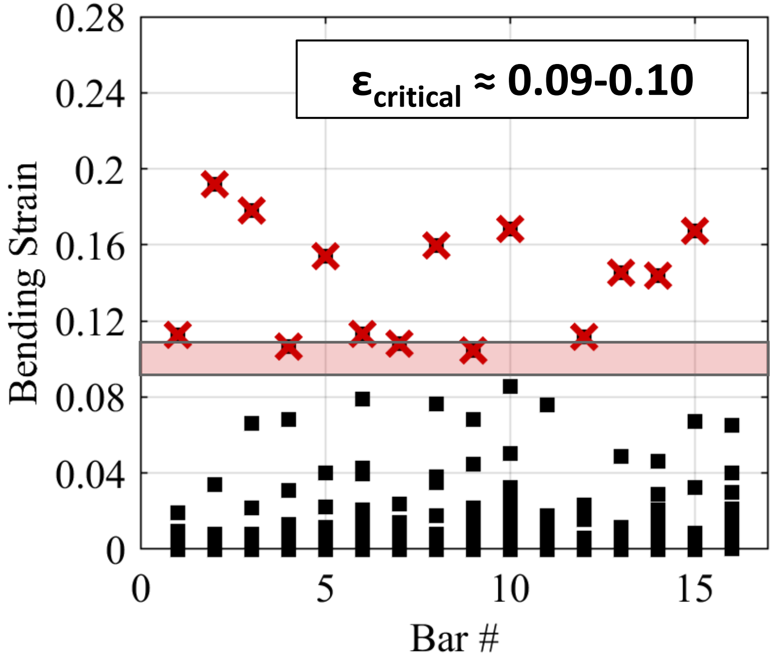
Difference in displacement capacity and post-buckling behavior attributed to “bending strain capacity”



Grade 60 Columns

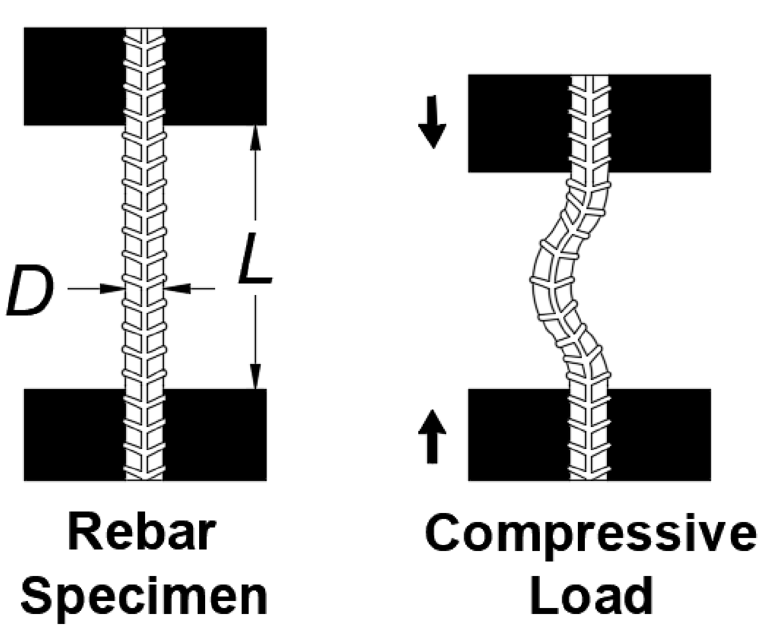


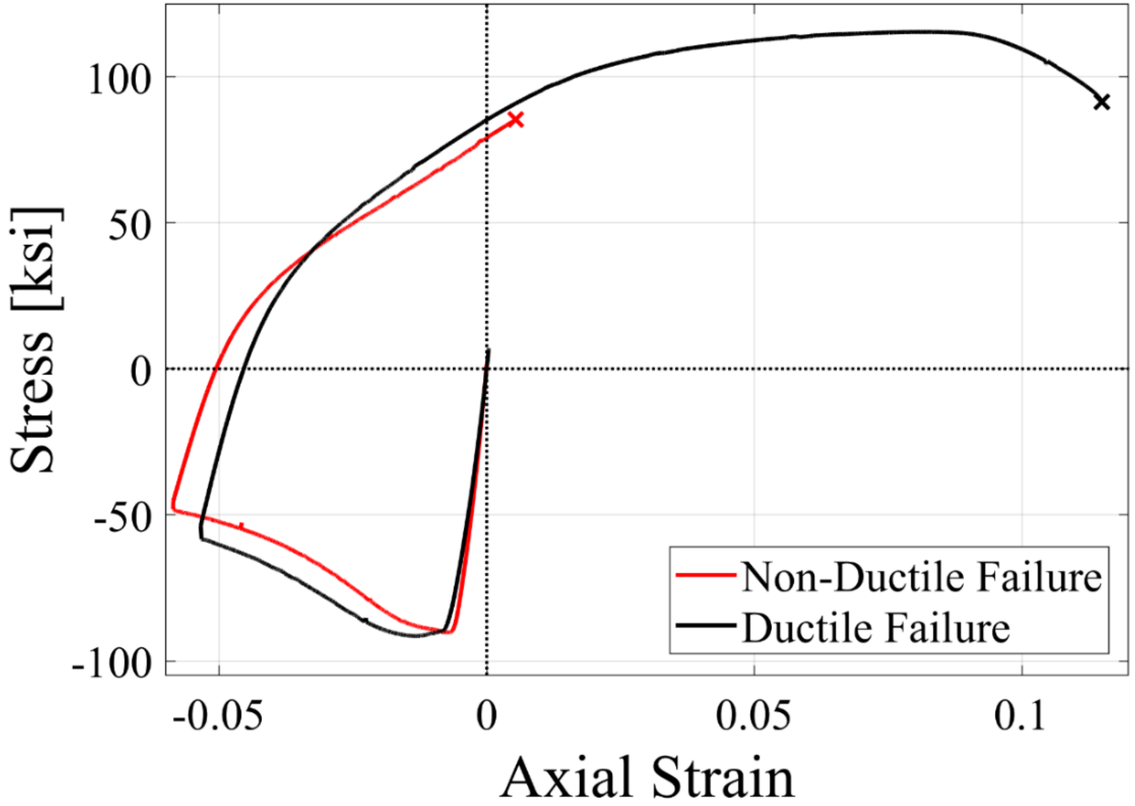
Grade 80 Columns



Barcley and Kowalsky (2018)

The "Buckled Bar Tension Test" ("BBT Test") was developed to simulate bending and tension strain demands on buckled bar

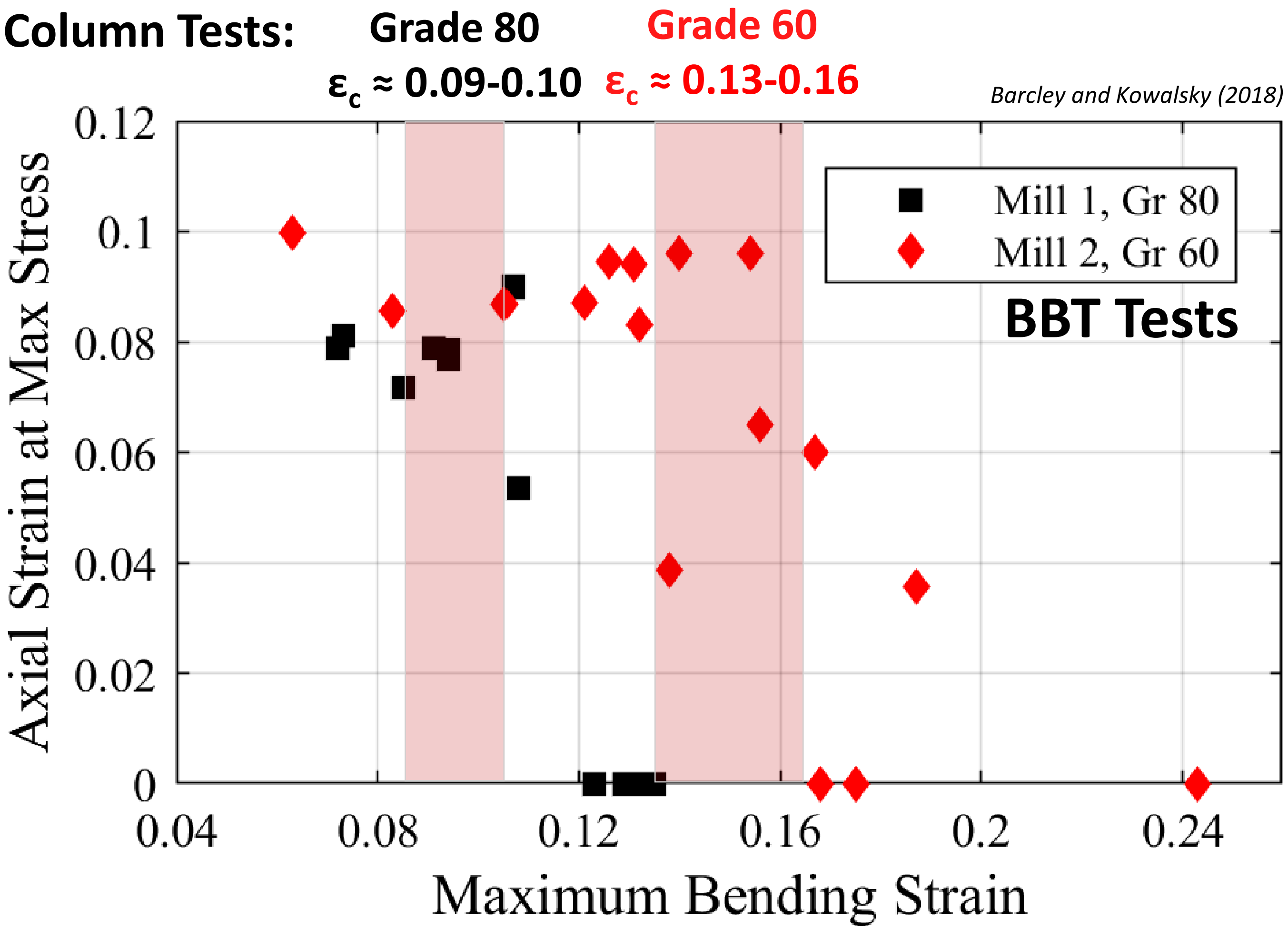




If buckled to a high enough curvature, the bar will experience a brittle failure upon tension loading

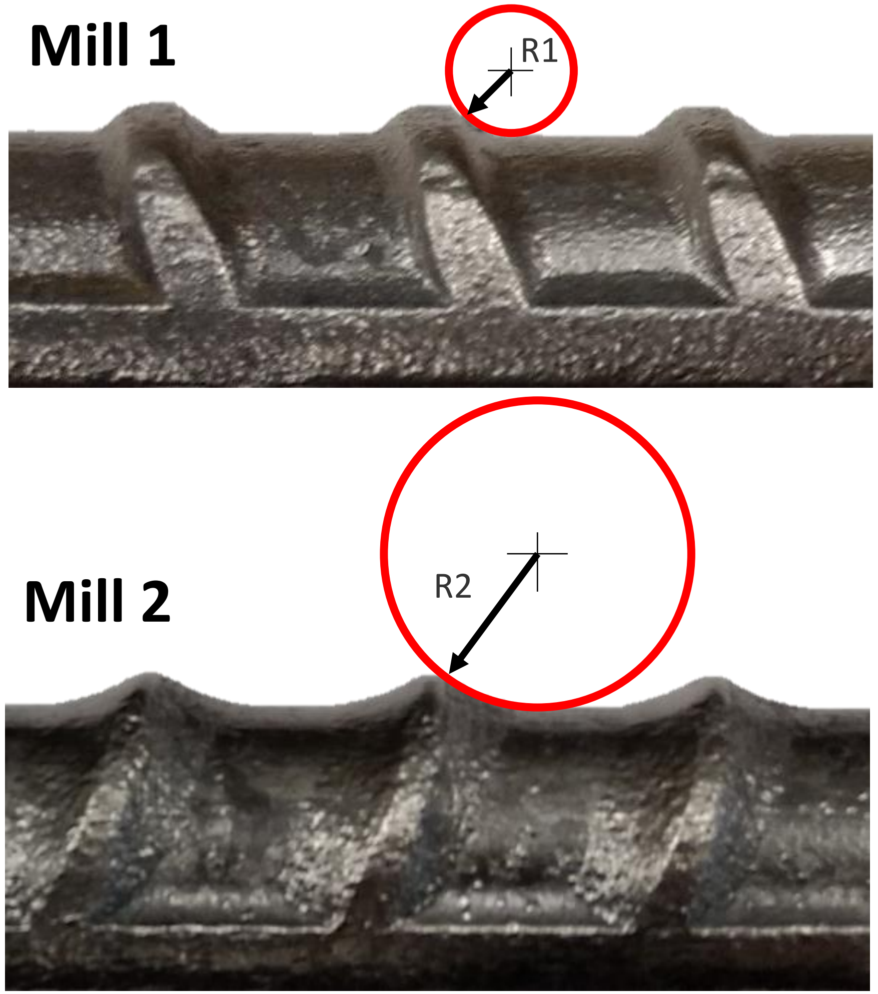
Barcley and Kowalsky (2018)

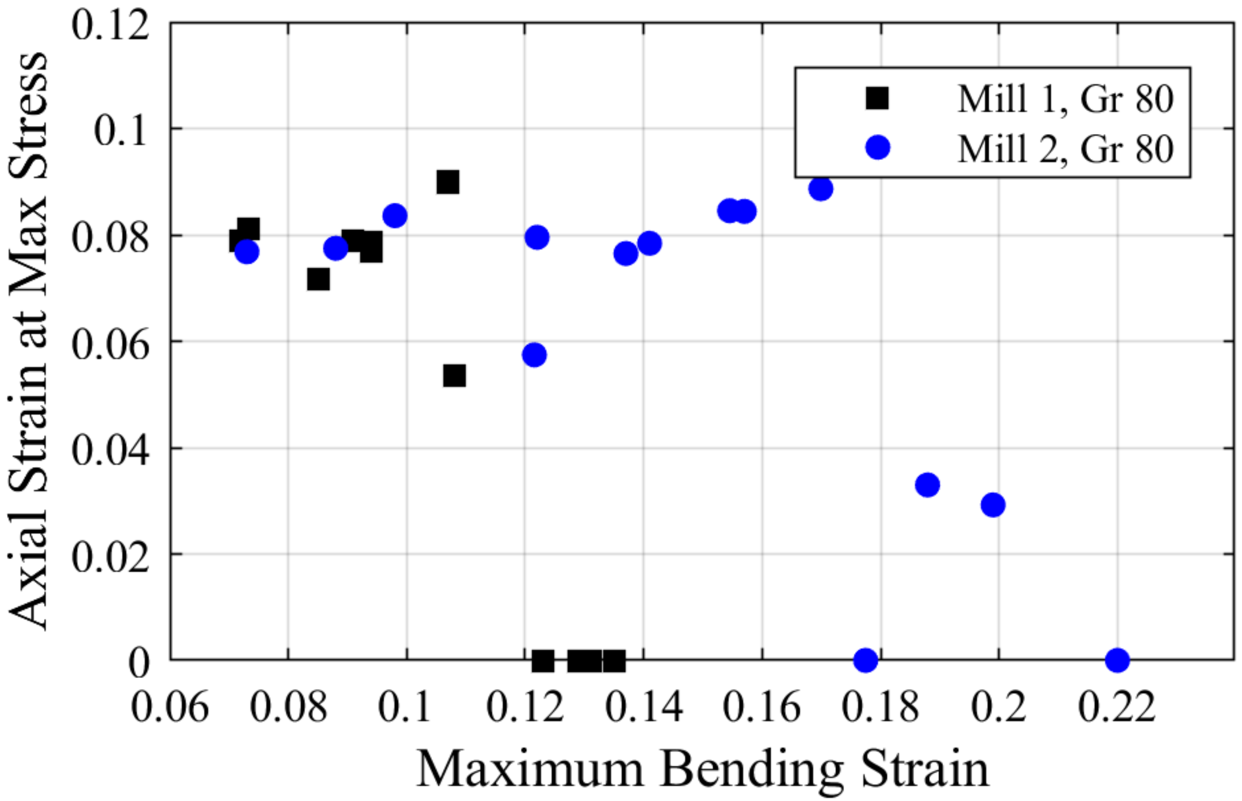
BBT results correlate with column tests and could be an indication of column performance



BBT tests were conducted on various reinforcing steel from different mills

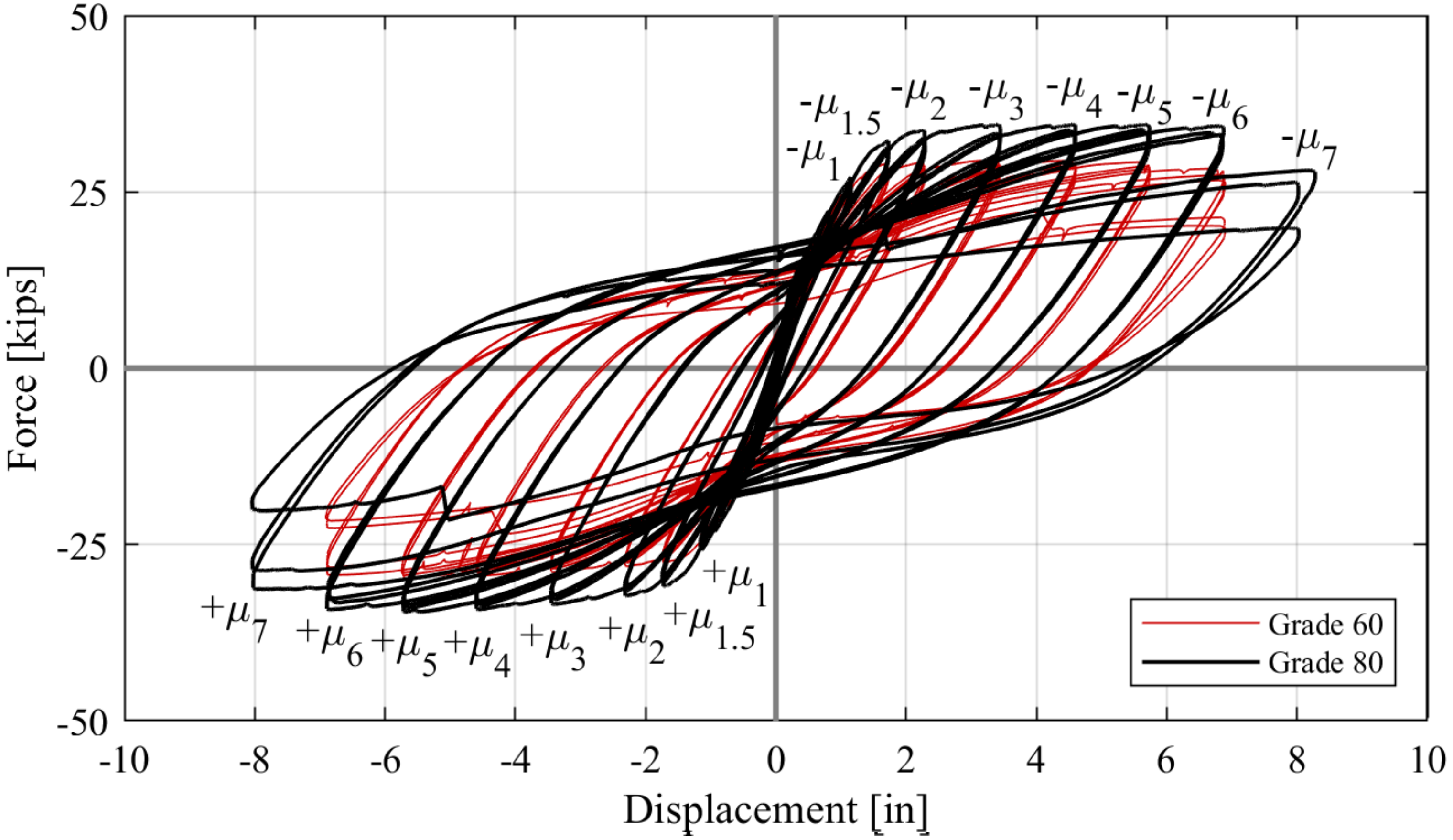
Mill 2 had a much smoother rib radius than original column steel, which led to better performance

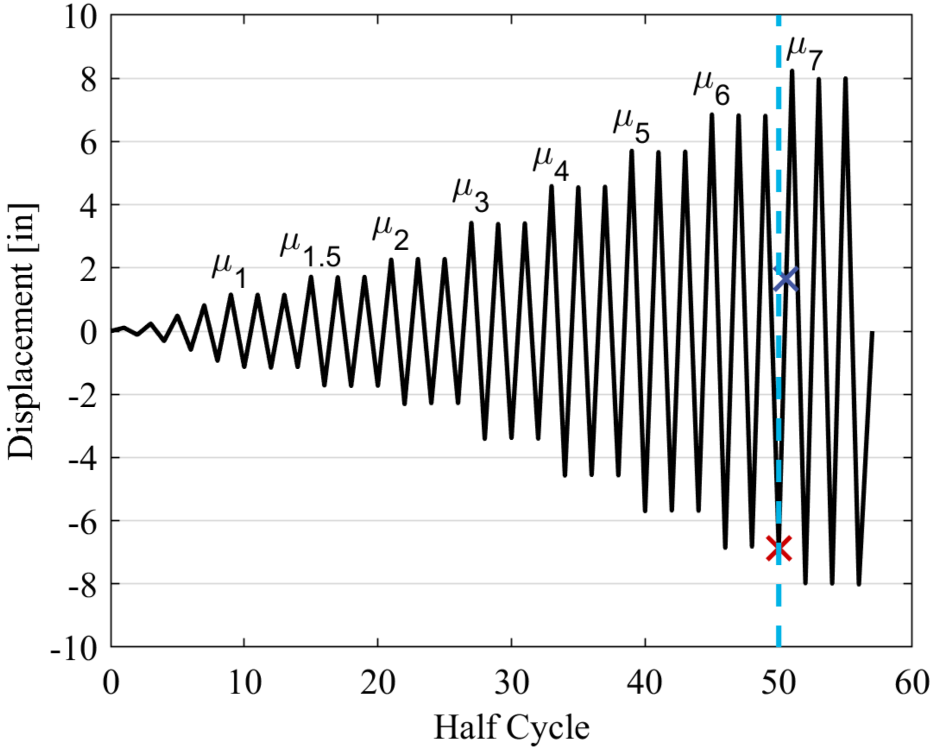




Barcley and Kowalsky (2018)

The Mill 2 Grade 80 column reached a full ductility cycle beyond the Grade 60 column





8 ft column, ALR = 10%

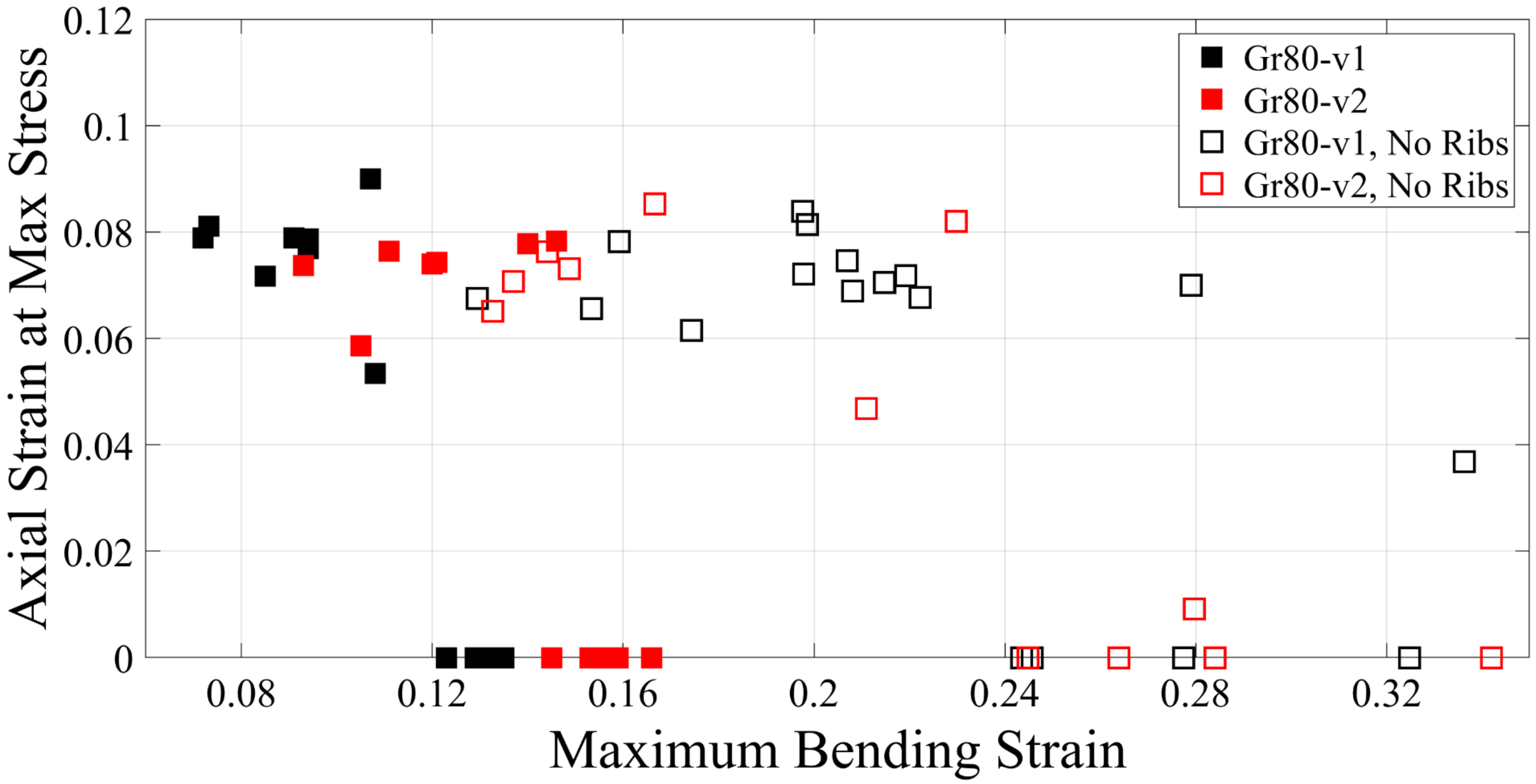
Larger Rib Radius

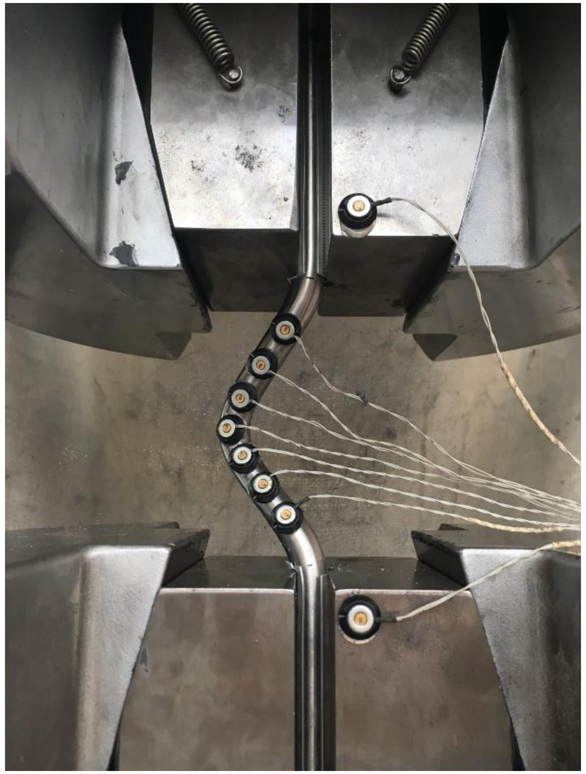
First fracture:

× μ_6^{3-} = -6.87” (Gr 60)

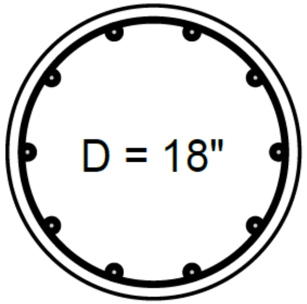
× μ_7^{1+} = 8.02” (Gr 80)

BBT Tests on smooth bars resulted in higher bending strain compared to typical rebar



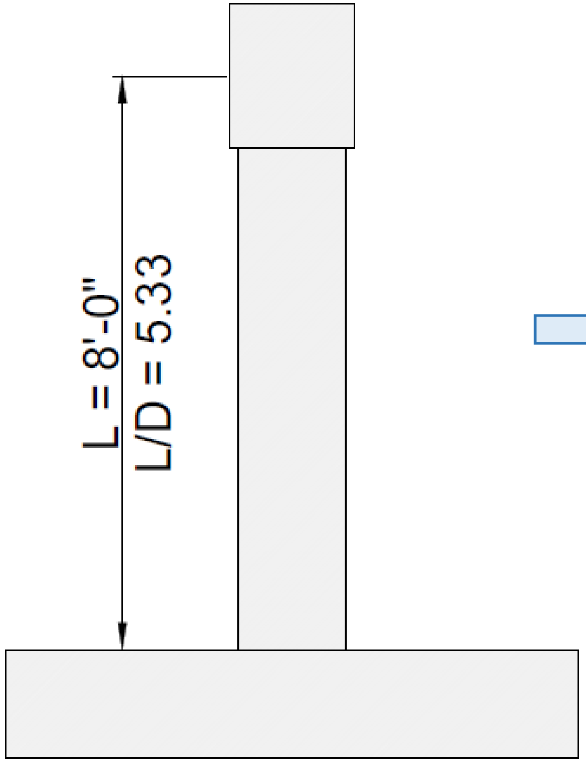


Two large-scale reverse cyclic columns tests reinforced with Grade 80 steel with unconventional detailing were conducted



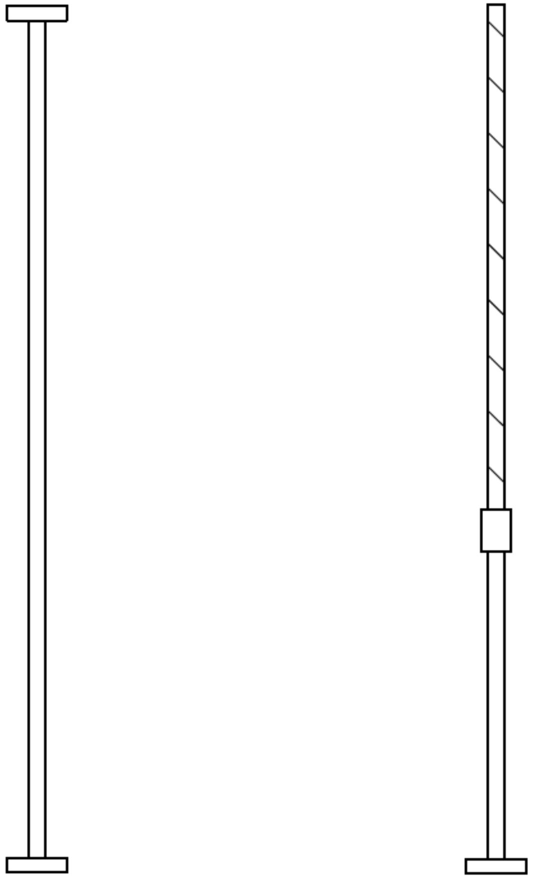
(10) #7 (2.4%)
#3 @ 2” (1.3%)

(2)
8 ft columns
ALR = 15%



Smooth headed bars

Smooth bar in the plastic hinge



Comparison Grade 60 columns have matched strength

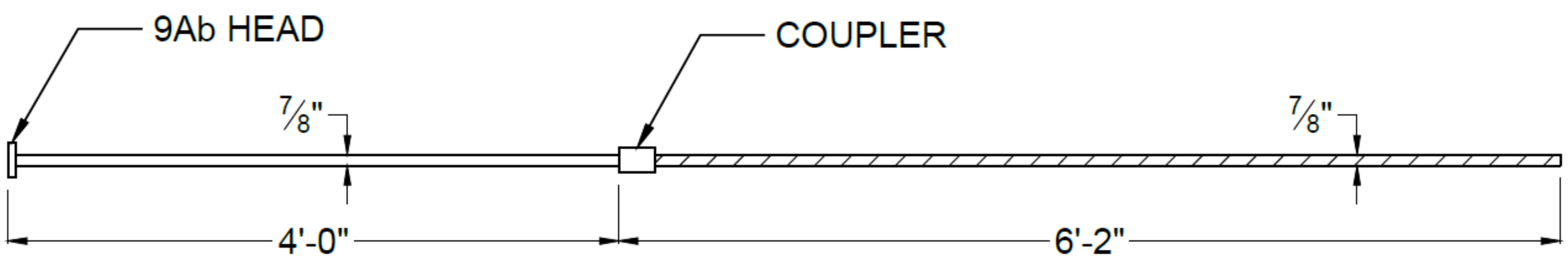
Comparison Grade 80 columns have matched detailing

Columns were constructed with smooth bar in two different ways:

Smooth headed bar

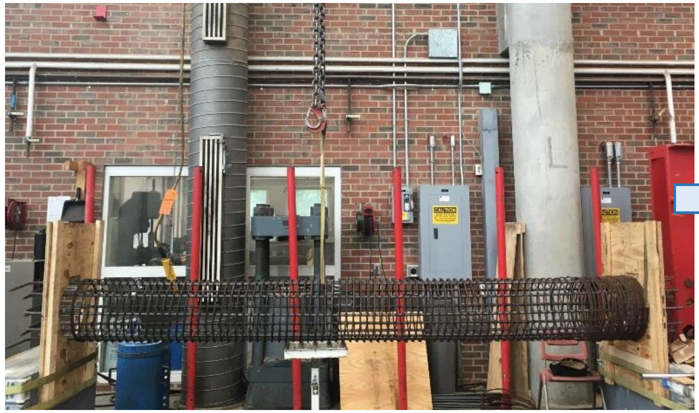
Will allow for ease of constructability to implement in practice

Smooth bar in the plastic region only



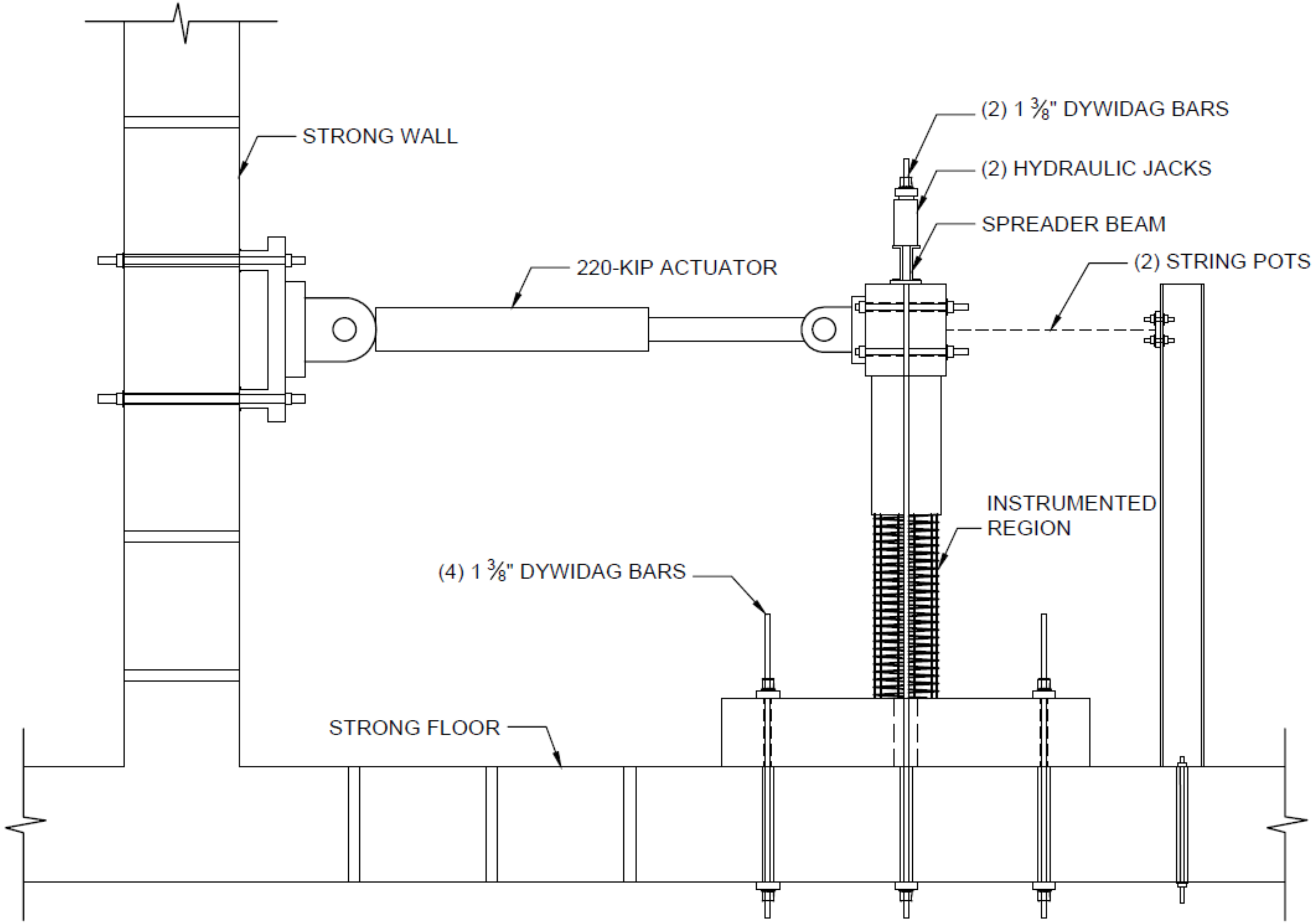
Will continue to have friction bond from the ribs outside the plastic hinge

Column Construction Process



Testing was completed this month, March 2022

Columns are subjected to quasi-static, unidirectional, 3 cycle loading

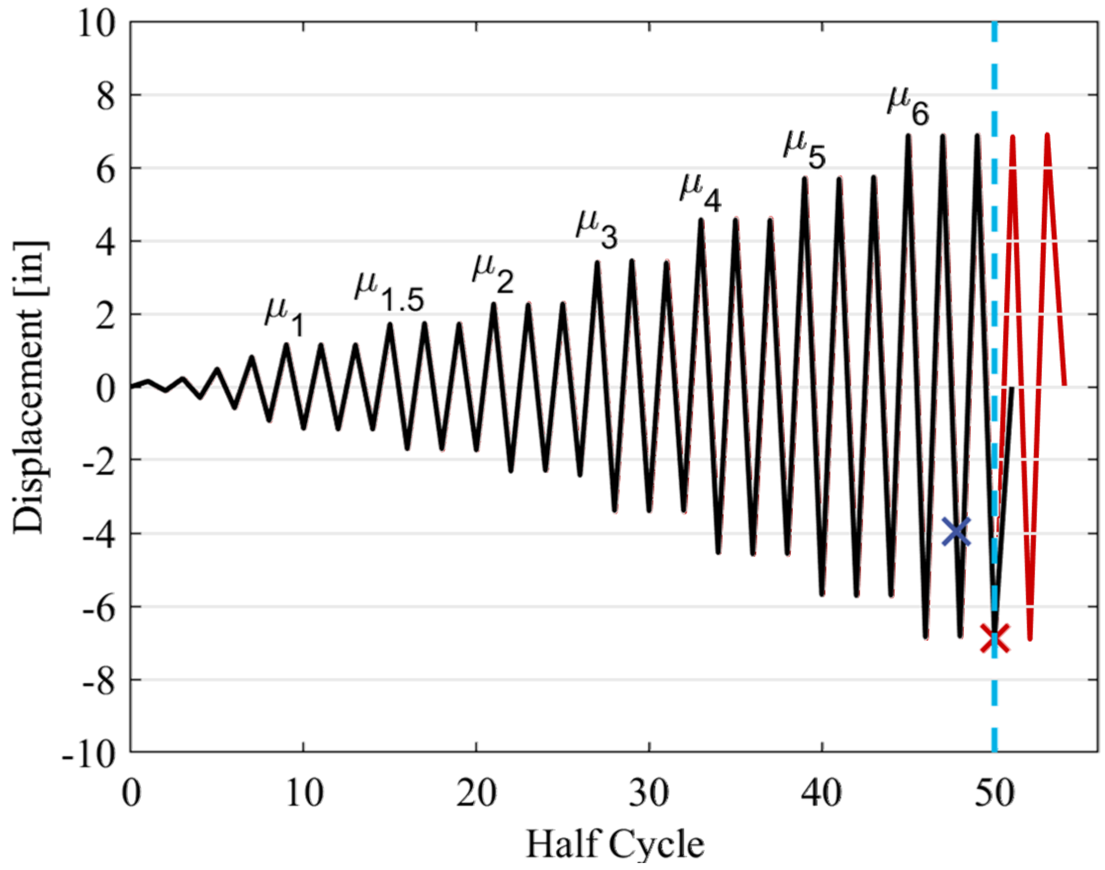


Optotrak (NDI) LEDs allow for 3-D position data of longitudinal and transverse steel

To directly compare to traditionally reinforced comparison columns, these columns match the exact:

Displacement Load History

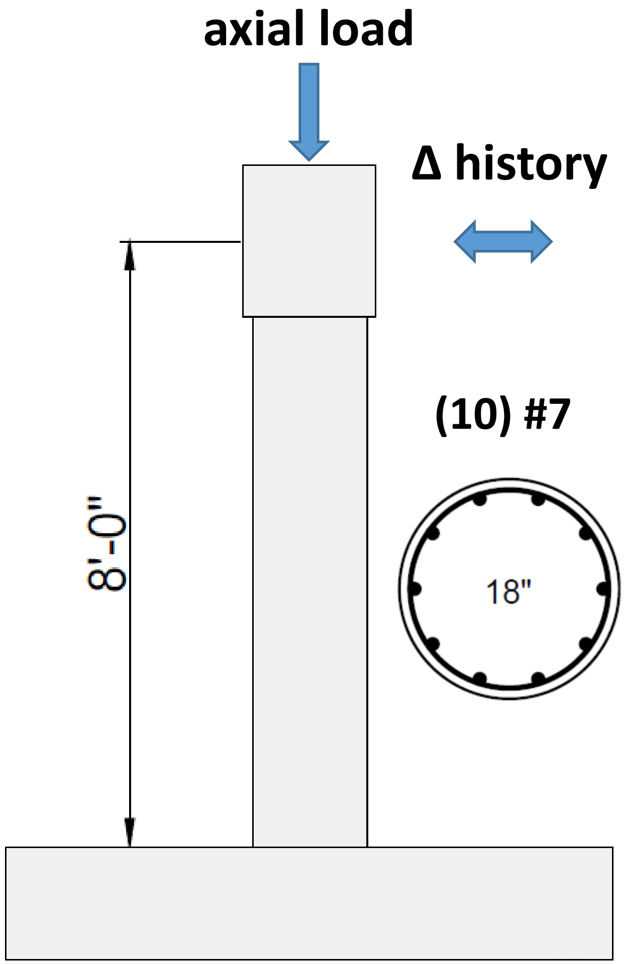
The ductility values are not integers due to different yield points



Axial Load

Axial load ratio may not be round number due to different concrete strengths

Three column tests will be compared to different detailing of the longitudinal reinforcing steel detailing

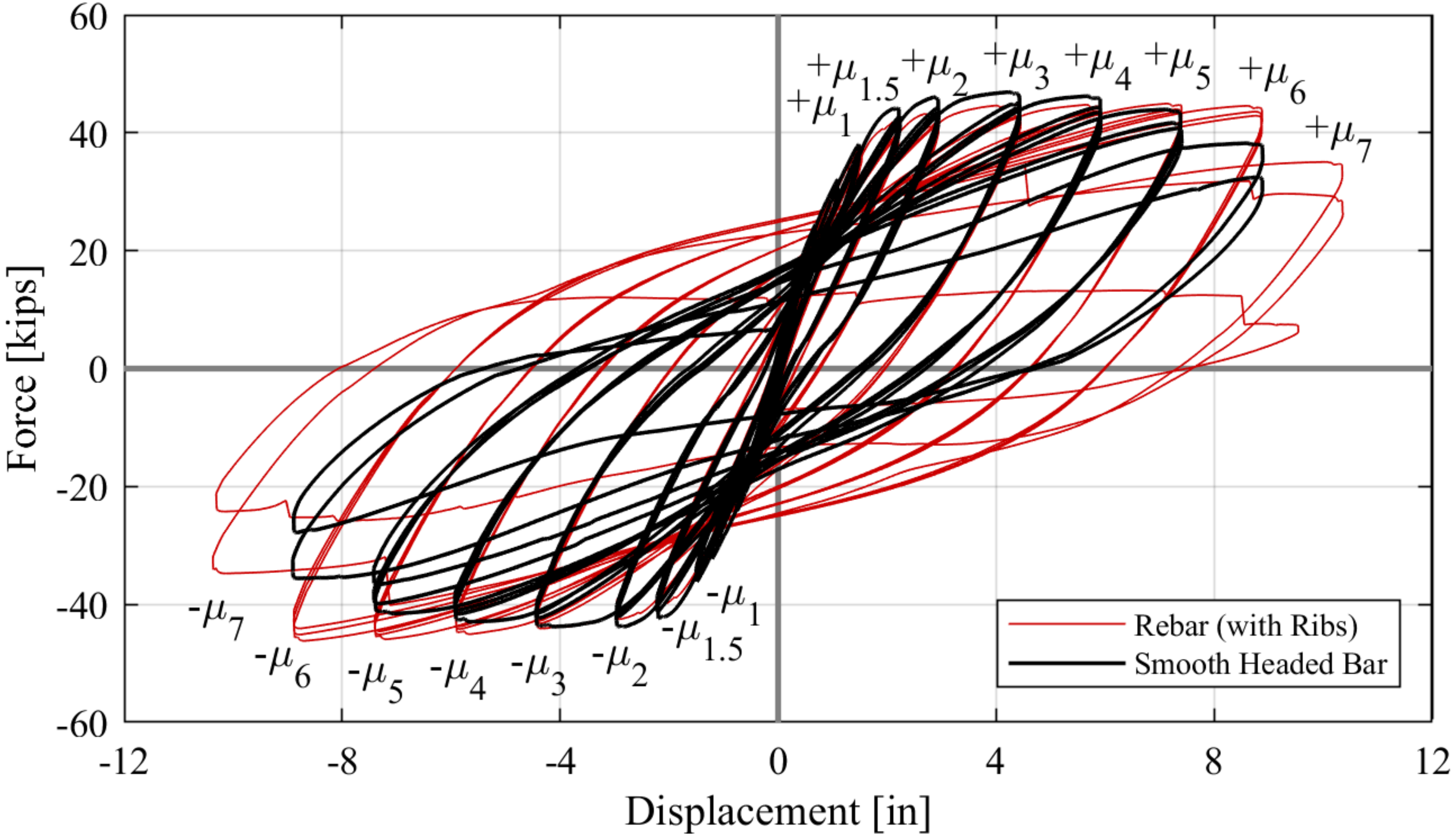


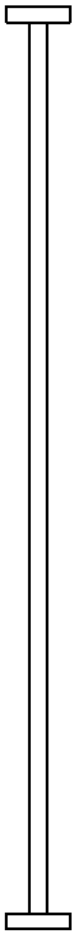
Rebar (with Ribs)

Smooth Headed Bar

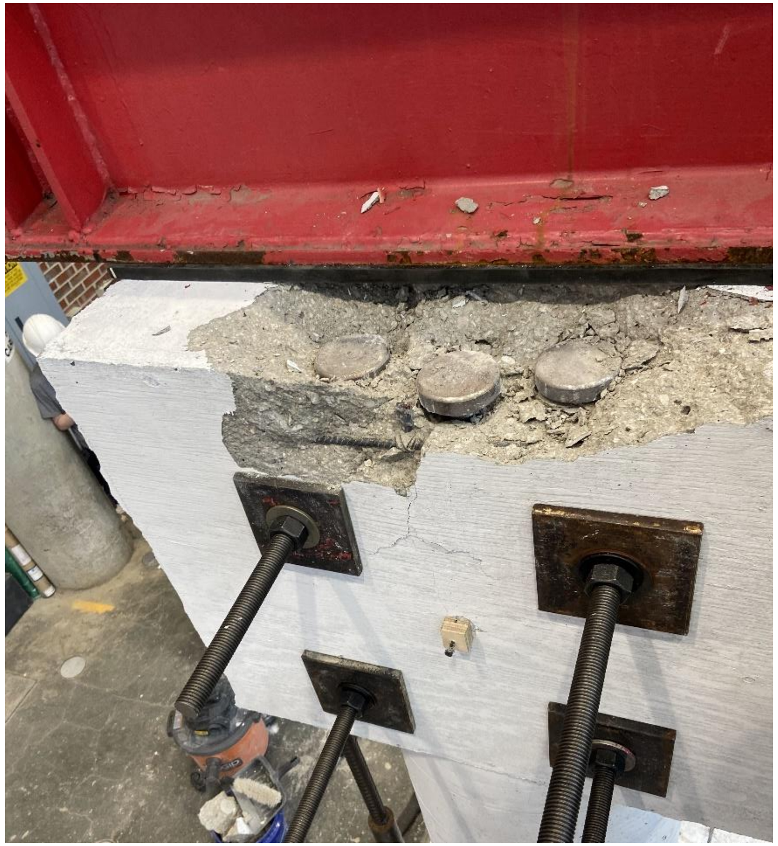
Smooth Bar in the Plastic Hinge

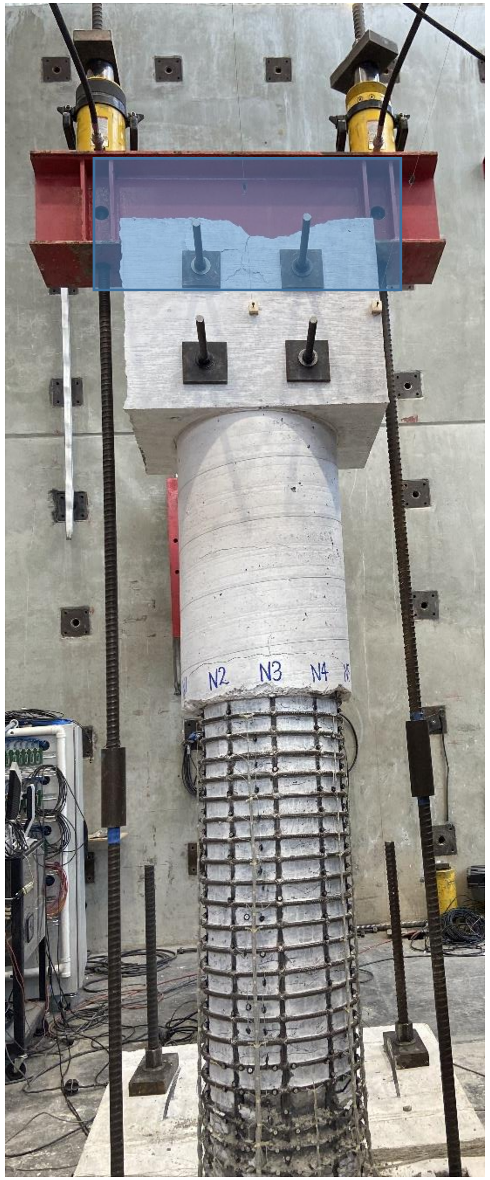
The smooth headed bar test had significant slip of longitudinal bars resulting in less energy dissipation



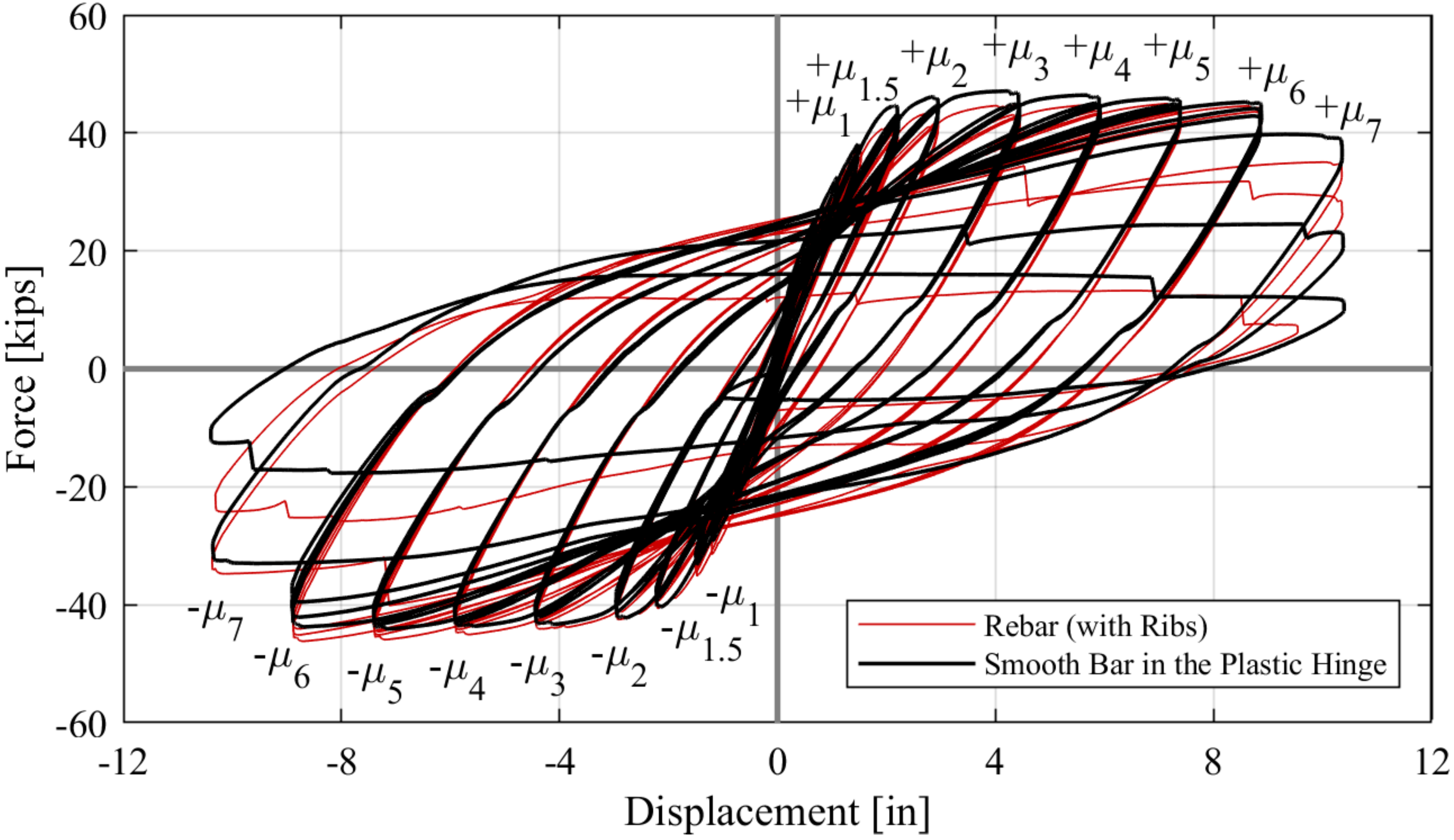


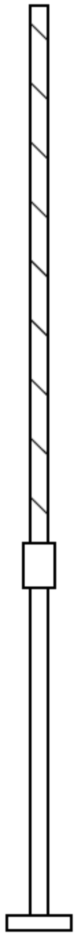
The test concluded due to punch out of headed smooth bars out of the cap beam



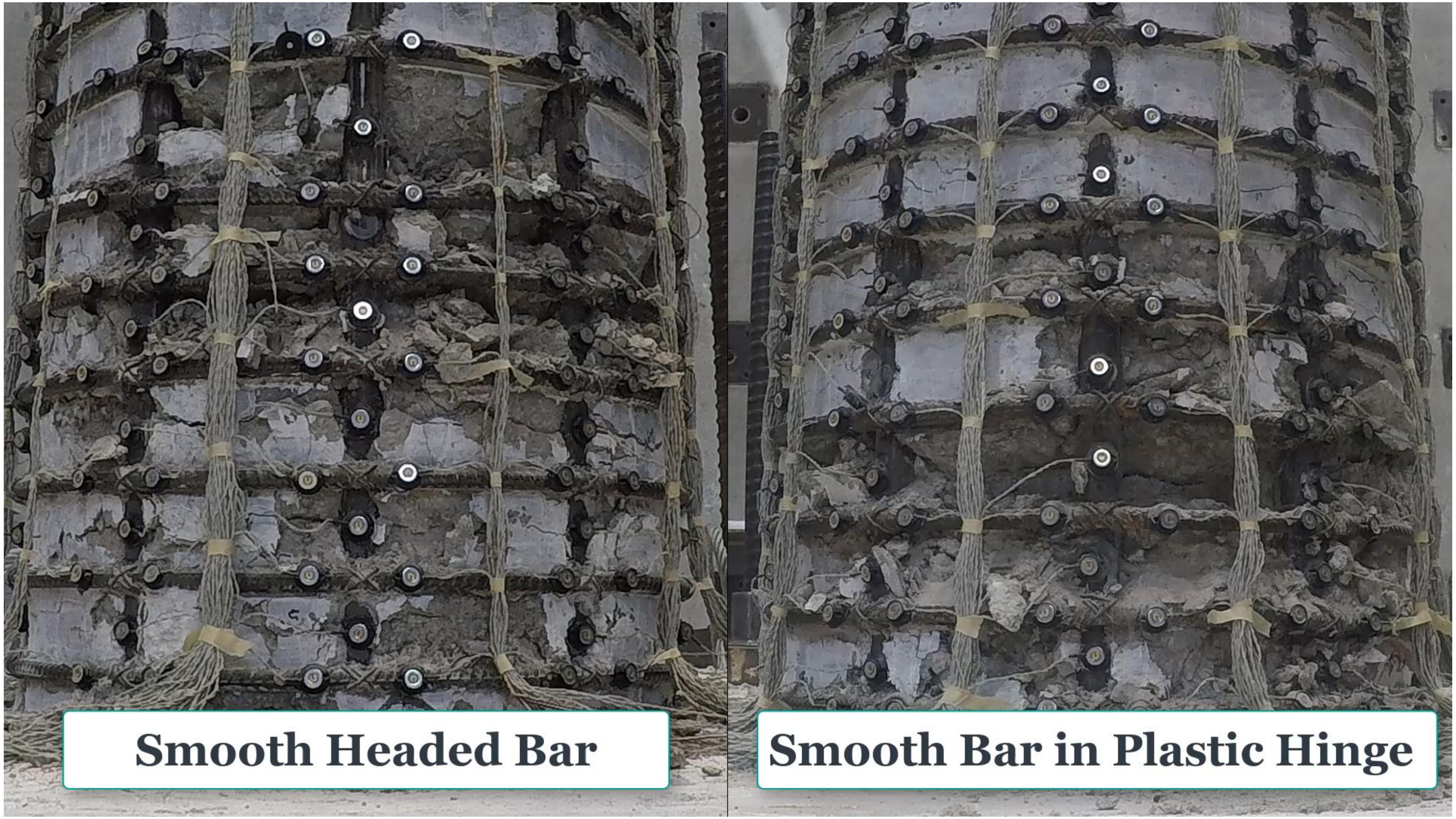


The smooth bar in the plastic hinge resulted in similar force-displacement as the test with ribs but delayed fracture after buckling

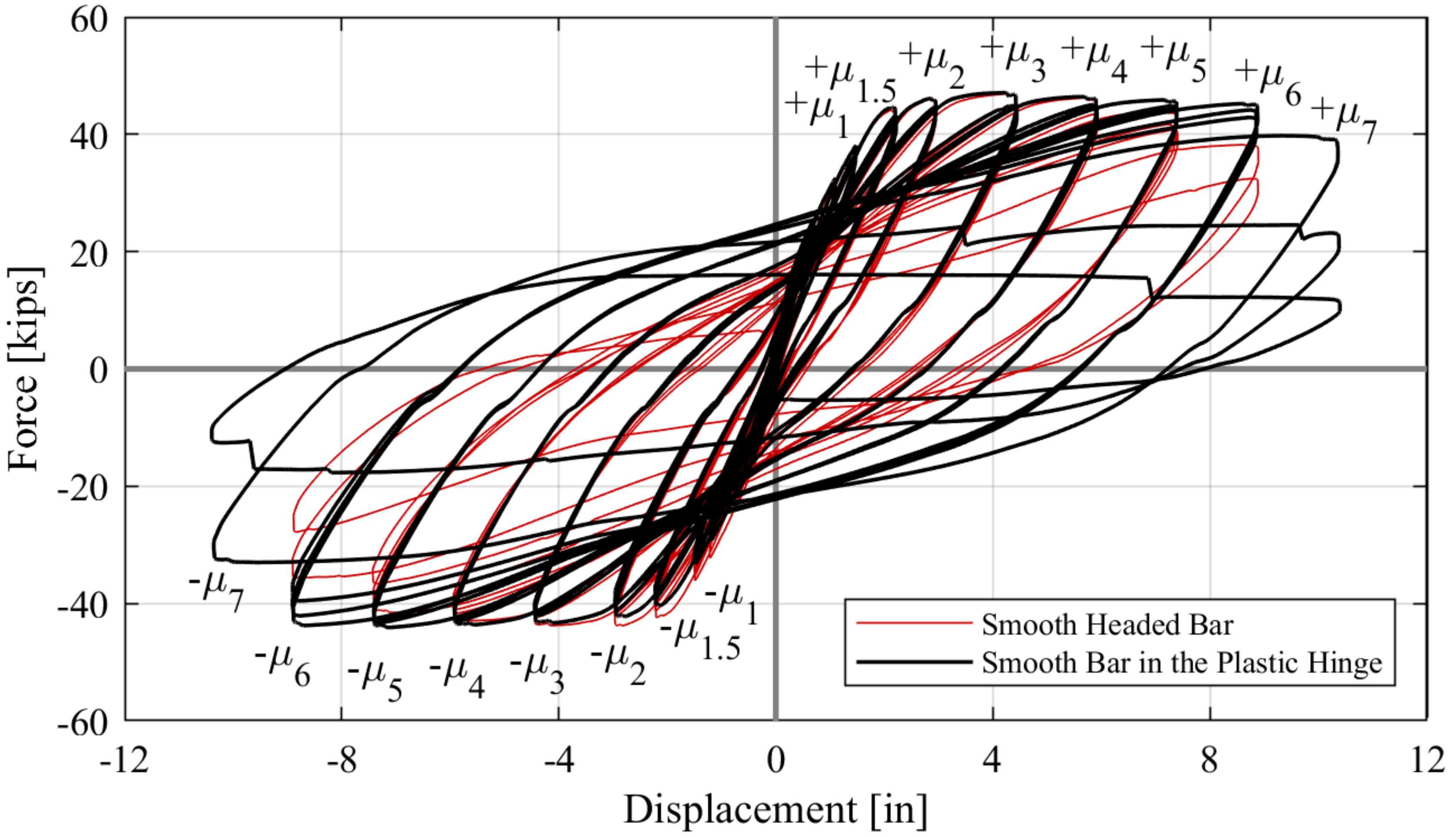




The smooth headed bar slipped significantly while the smooth bar in the plastic hinge failed in fracture of a buckled bar

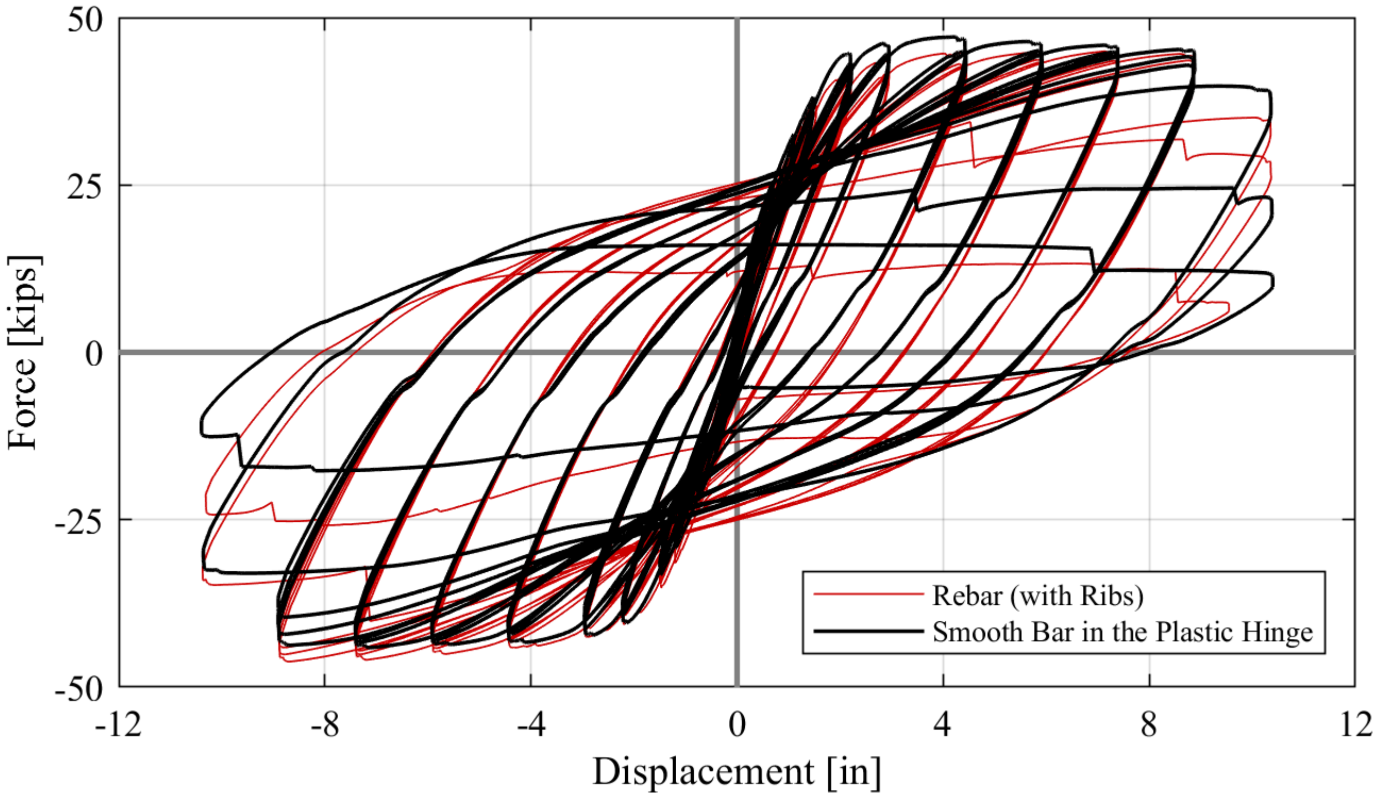


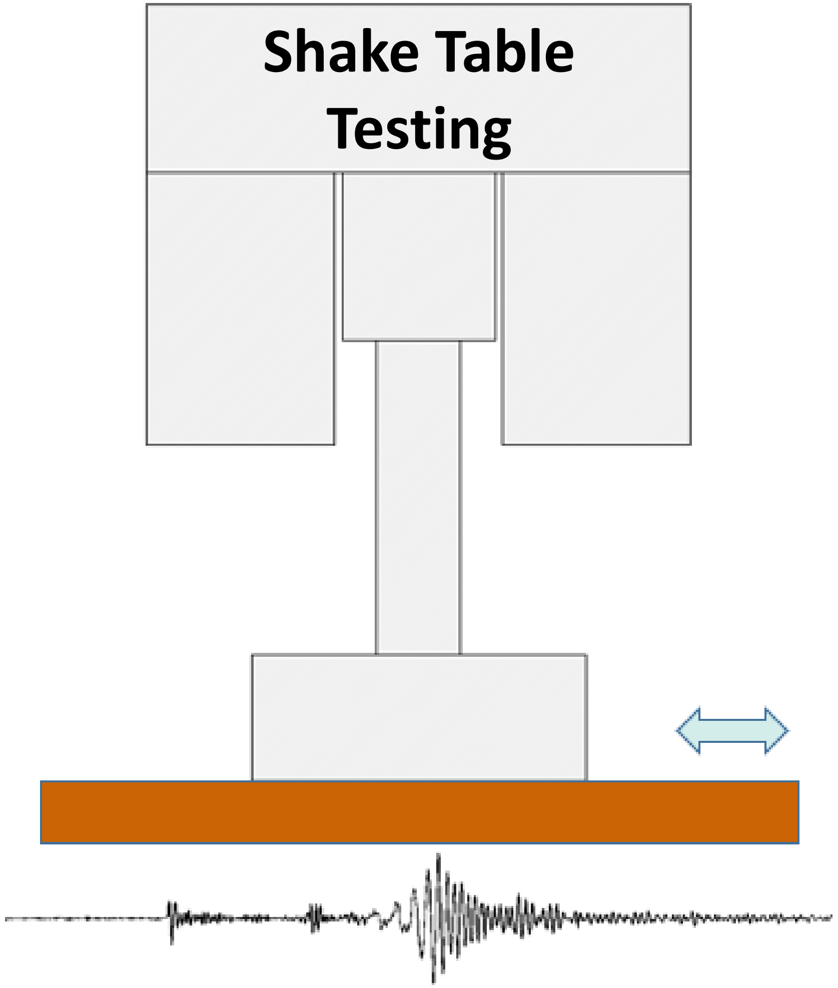
Unconventional detailing such as smooth bar in the plastic hinge is comparable to the seismic performance of a traditional column



Further consideration is required to prevent punch out failure of the smooth headed bar

Future dynamic tests will be conducted on a shake table to further demonstrate the performance of unconventional detailing





Questions?

This project is funded by the California Department of Transportation. The support from the students and technical staff at the CFL is also greatly appreciated.